Physical Geography 110

Portraits of a Planet

Unit 4G: The Structure of the Earth

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PURPOSE

Key questions of the unit:

What is the internal structure of the earth?

How was our knowledge of that structure obtained?

Unit Objectives:

Students will be able to:

1. explain the source and consequences of the Earth's internal heat.

2. explain how knowledge of the earth's internal structure has been obtained.

3. describe the internal structure of the earth's interior and its significance.

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What we have learned thus far:

- The earth has different layers that are made of different materials, with different densities.

- Some of the earth's layers are in a liquid state, while some are more solid.

Questions we hope to answer after today:

1. How do we know what the centre of Earth is made of and what it looks like?

2. What sort of equipment and scientific processes are used?

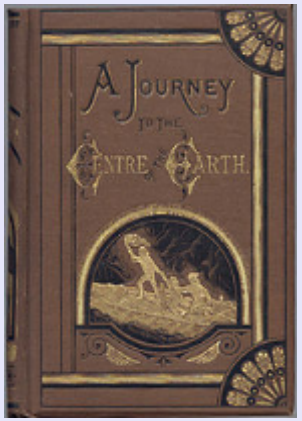
3. What questions got it all started?

References: Birchall, G. & McCutcheon, J. (2003). Planet Earth: A physical georgraphy. Toronto: John Wiley & Sons.

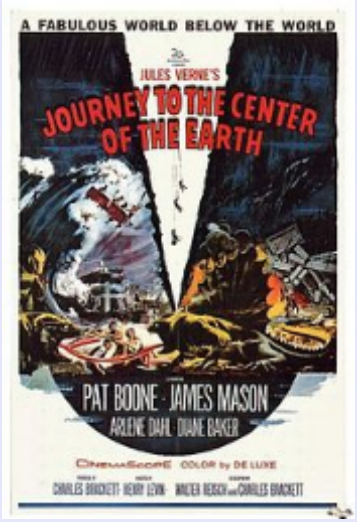
dreamstime.com

Jules Verne - Journey to the Centre of the Earth

1864



1959



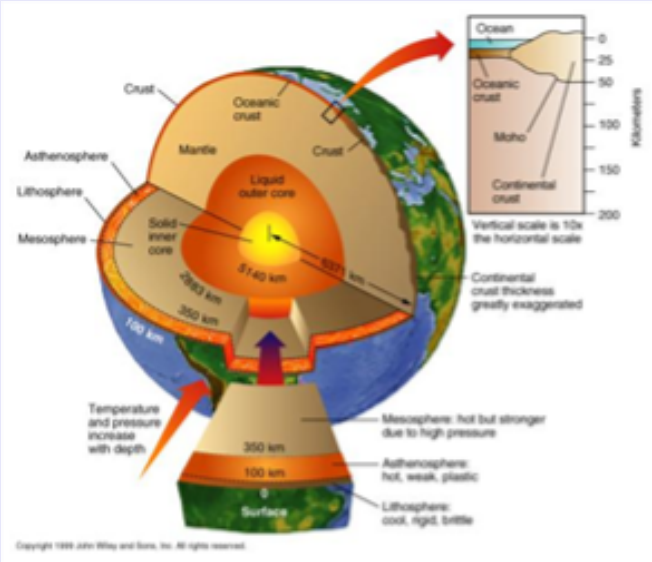
http://www.youtube.com/watch?v=WF8Bf1d_crk&feature=related

2008

A Journey to the Center of the Earth is a classic 1864 science fiction novel by Jules Verne. The story involves a German professor (Otto Lidenbrock in the original French version, Professor Von Hardwigg in the most common English version) who believes there are volcanic tubes going toward the center of the Earth. He, his nephew Axel, and their guide Hans encounter many adventures, including prehistoric animals and natural hazards, eventually coming to the surface again in southern Italy. Click on the link to the right to see the movie trailer!

- http://en.wikipedia.org/wiki/A_Journey_to_the_Center_of_the_Earth. May 18th, 2011.

YOUR JOURNEY TO THE CENTRE



<u>Directions</u>: Answer the following questions. You may use a drawing with details, or a short descriptive paragraph.

If you were to travel to the centre of the earth,

1. What would your vehicle, vessel, etc. look like?

2. What factors would you have to consider in the building of this vehicle / what features does it have?

3. What route would you take?

<u>Activity taken from:</u> Birchall, G. & McCutcheon, J. (2003). *Planet Earth: A physical georgraphy*. Toronto: John Wiley & Sons.

<u>Picture from:</u> http://www.google.ca/imgres?imgurl=http://2.bp.blogspot.com/_O8FA1ndvaaM/TTfBsYt9kuI/AAAAAAAAABw/r3EVX8u9sdM/s1600/m5.jpg&imgrefurl=http://greenearthbd.blogspot.com/2011/01/internal-structure-of-earth.html&usg=__A0TIuuN01Scfnyayc2oVEK99FGo=&h=482&w=557&sz=38&hl=en&start=0&zoom=1&tbnid=4cjHCMNlxC4giM:&tbnh=175&tbnw=202&ei=797TTaPvEMft0gG26cn7Cw&prev=/search%3Fq%3Dstructure%2Bof%2Bthe%2Bearth%26um%3D1%26hl%3Den%26sa%3DN%26biw%3D1366%26bih%3D667%26tbm%3Disch0%2C105&um=1&itbs=1&iact=hc&vpx=152&vpy=343&dur=3645&hovh=209&hovw=241&tx=136&ty=120&sqi=2&page=1&ndsp=18&ved=1t:429,r:12,s:0&biw=1366&bih=667

THE INTERIOR OF THE EARTH

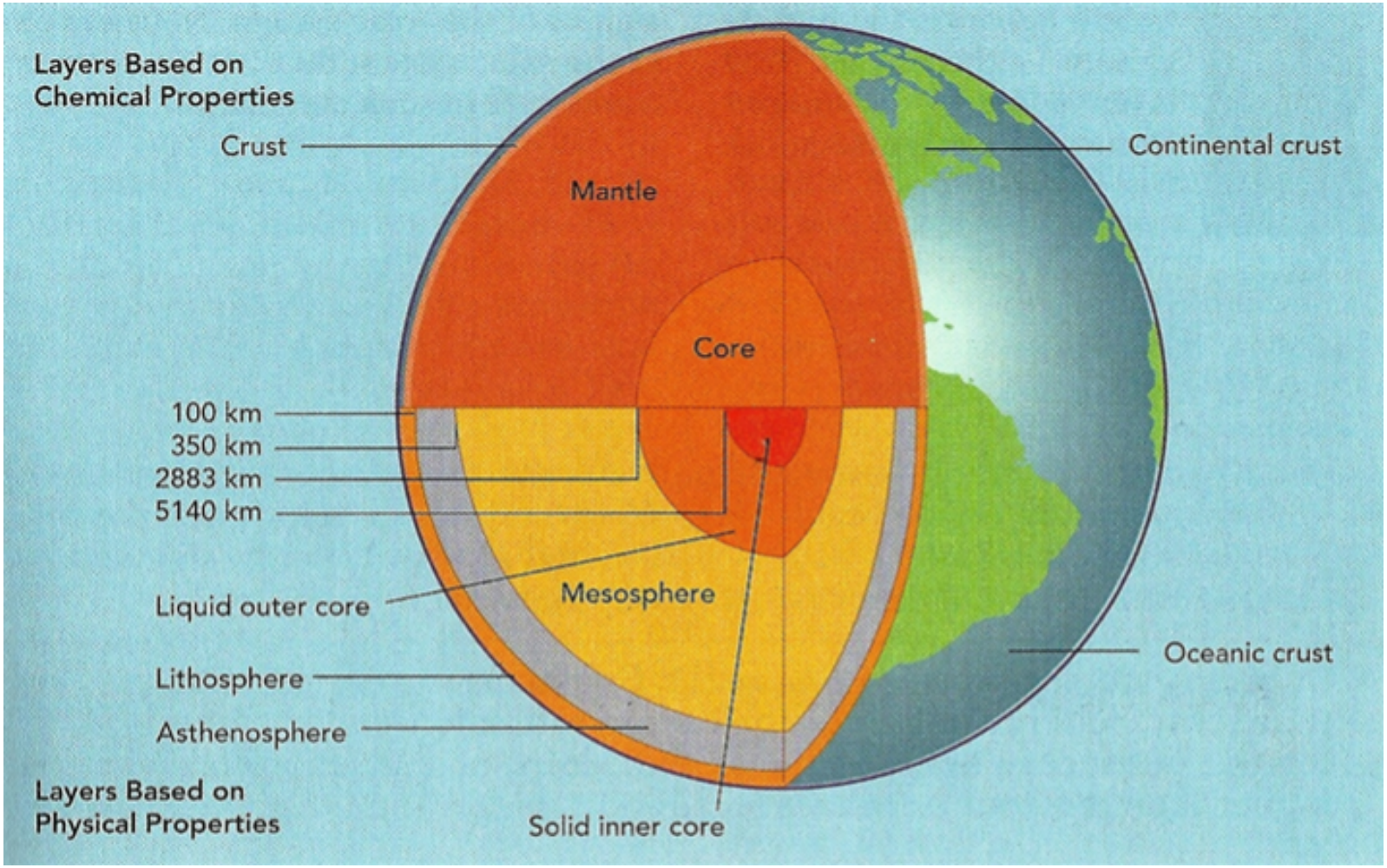


Photo from: Birchall, G. & McCutcheon, J. (2003). *Planet Earth: A physical georgraphy*. Toronto: John Wiley & Sons.

HOW DO WE KNOW?

Scientists can only make predictions. In textbooks, you will see phrases like:

"the core of the earth is *believed* to be composed of..." (p. 54 - Planet Earth).

"the temperature of the core is *estimated* to be at least 4500°C for the outer core..." (p. 56 - Planet Earth).

The many predictions come from what they figure "makes sense."

For example: "scientists believe the asthenosphere is in a plastic state, part liquid and part solid. If this is not so, it would be difficult to explain the movements of the continents!" (p. 55 - Planet Earth). *Think about earthquakes and the movement of tectonic plates.*

WHAT DO YOU THINK?

If you were a scientist, assigned the task of determining what was at the middle of this planet, what field might you be working in?

GEOPHYSICS - Geophysics is a field that integrates geology, mathematics, and physics in order to understand how the Earth works. Geophysicists study Earth processes through a combination of laboratory experiments, computational and theoretical modeling, remote imaging, and direct observation.

Reference: Homepage. (2011). School of Earth Science. Department of Geophysics. Standford University. http://geophysics.stanford.edu/

HISTORY OF GEOPHYSICS

Motivations for study:

1. Curiosity - about the earth and its components, as well as events and hazards. What would be some examples?

2. Economical / Use of earth's resources. Such as what exactly?

Theories:

Since ancient times, people have wondered about what is in the centre of the earth. Some were based on the ancient concept of subterranian "places" or chambers, like Greek "Hades," Christian "Hell," or Jewish "Sheol."

REMEMBER THIS FELLOW?

Edmund Halley

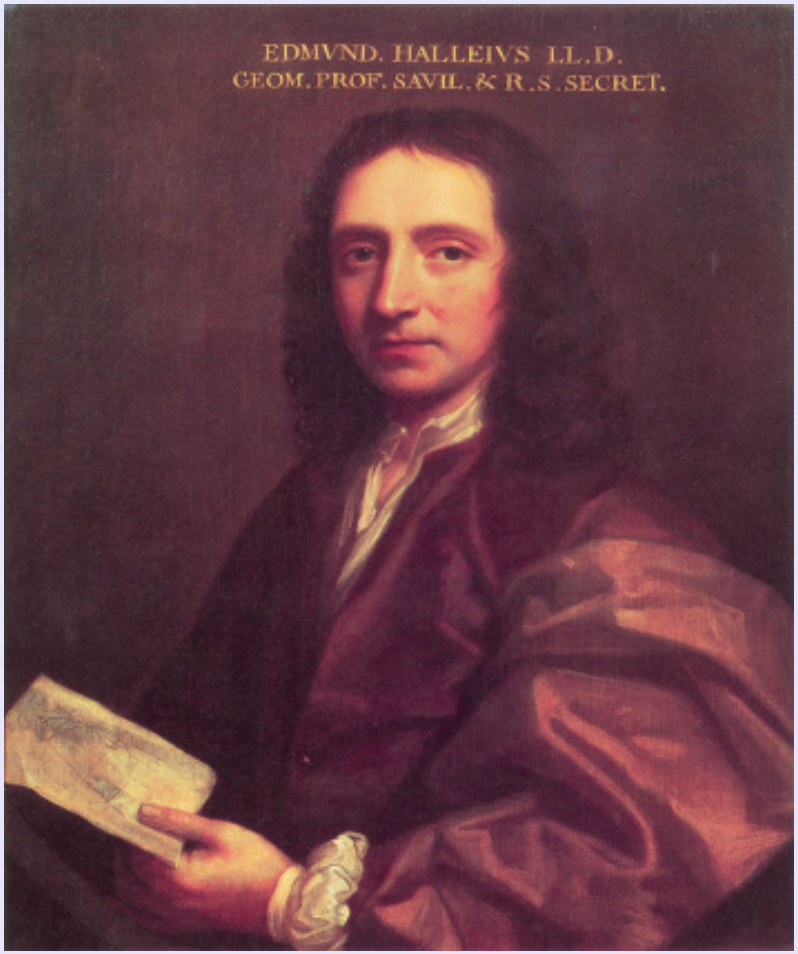
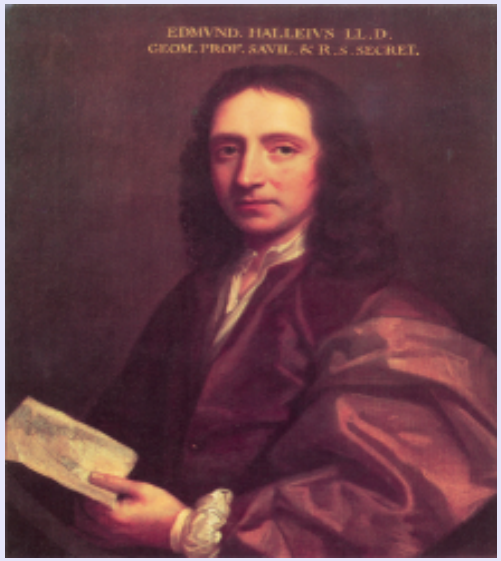


Image from: http://commons.wikimedia.org/wiki/File:Edmund_Halley.gif



HOLLOW EARTH THEORY

In 1692, Edmund Halley proposed that the earth consisted of a hollow shell, which he estimated to be about 800 km (roughly 500 miles) thick.

Halley's hypothesis suggested that, within the shell, there were two inner concentric shells (having a common axis) and an inner core. He believed that fluids and atmosphere separated the shells from each other, and that gas escaping from the atmosphere to the surface is what caused the Aurora Borealis.

According to Halley, each shell had its own magnetic poles and rotated at different speeds. He proposed this to be so, in order to explain inconsistent compass readings.

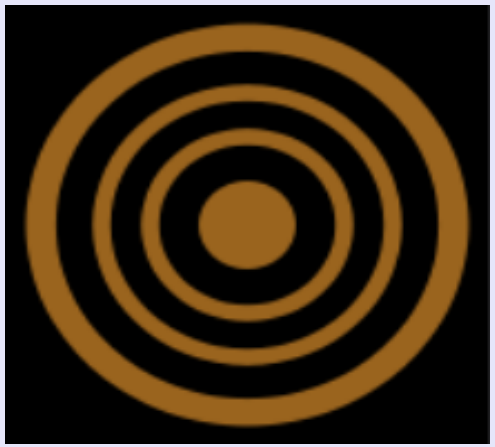


Image from: http://commons.wikimedia.org/wiki/File:Hollow_Earth.svg

Sources: Griffin, Duane. What Curiosity in the Structure: The Hollow Earth in Science. Bucknell University Department of Geography.
http://en.wikipedia.org/wiki/Hollow_Earth

Hollow Earth Theories

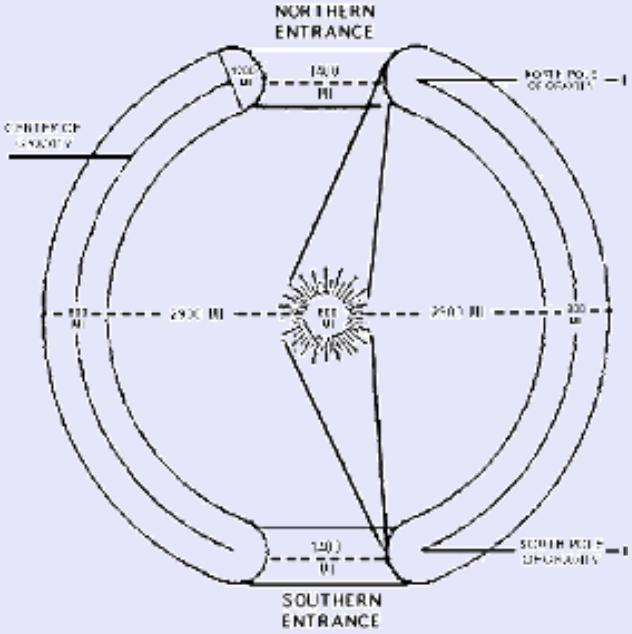
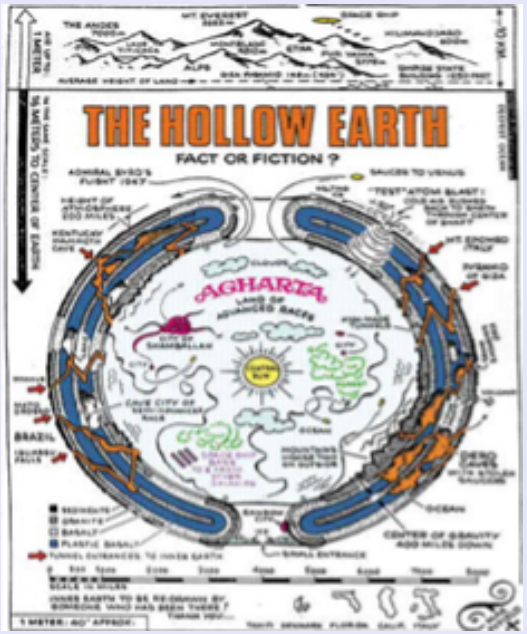


Image from: http://www.v-j-enterprises.com/holearth.html



Source: Sandifer, E. (April 2007). How Euler Did It. Euler and the hollow earth: fact or fiction? *MAA Online*. Retrieved from http://www.maa.org/editorial/euler/How%20Euler%20Did%20It%2042%20Hollow%20earth.pdf

Later theories were even more imaginative, and led to further hypotheses and subterranean works of fiction, such as the Jules Verne example we just looked at. With a partner, search one of these hypotheses on the internet. In ten minutes, you'll share your findings with the class.

HISTORY OF GEOPHYSICS

Technology has come a long way!

In the year 132 CE, Zhang Heng (what country was he from?) invented the "seismoscope." This instrument was designed to determine the direction of earthquakes. The instrument was equipped with dragons on its sides, and toads on the table surrounding it. A bronze ball would drop from the mouth of a dragon into the mouth of a toad. By looking at which of the eight toads had the ball, the direction of the earthquake could be determined.

Replica of Heng's seismoscope

http://en.wikipedia.org/wiki/File:EastHanSeismograph.JPG

Reference: Temple, Robert (2006). The Genius of China. Andre Deutsch. ISBN 0671620282.

Uncovering the Earth's Interior

Amongst the various depictions of earth's interior, how do we know what it's *really* like?

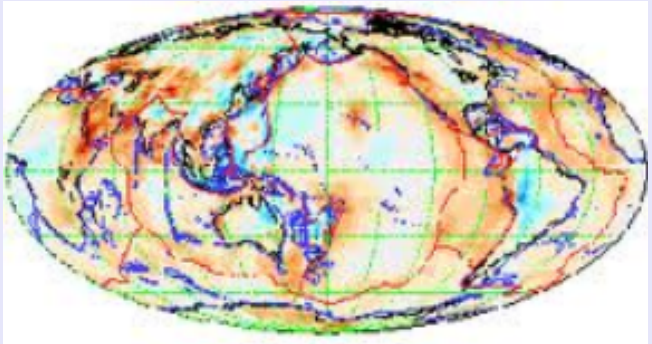


Image from: http://rses.anu.edu.au/students/index.php?p=project_finder&a=t&subject=Seismology

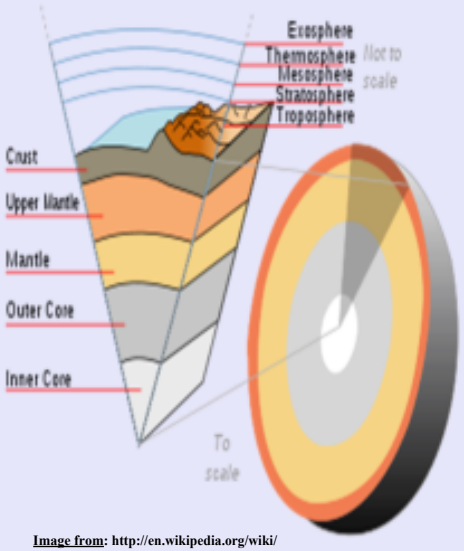


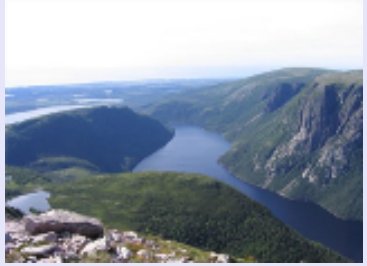
Image from: http://en.wikipedia.org/wiki/File:Earth-crust-cutaway-english.svg

Image from: http://commons.wikimedia.org/wiki/File:At_the_Earths_Core_cover.png

HOW DO WE KNOW?

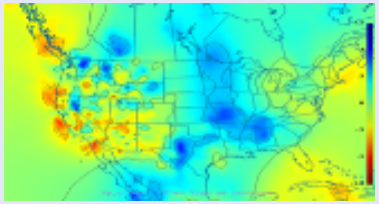
1. **DIRECT EVIDENCE**

   - Drill hole
   - Visible rocks



2. **INDIRECT EVIDENCE**

   - Meteorites
   - Seismology
   - Seismic Tomography



DIRECT EVIDENCE: The Kola Superdeep Borehole

- a drilling project of the former USSR that attempted to penetrate the earth's upper crust and sample the *Mohorovičić discontinuity*, or "Moho", where the crust meets the mantle

- drilling began in 1970, and a number of boreholes were drilled by branching from a central hole; the drill passed 12,000 m (39,000 feet) in 1983

- the deepest borehole is known as SG-3, and it reached a depth of 12,262 m (40,230 feet), the deepest hole ever drilled, and also the deepest artificial point on the earth

- temperatures were higher than expected at that depth 180 °C (356 °F), and the interior began to act more like a plastic than a solid, causing the hole to flow closed when the drill bit was removed

- if the hole had reached the initial goal of 15,000 m, it is estimated that the temperature would have reached a projected 300°C (572°F)

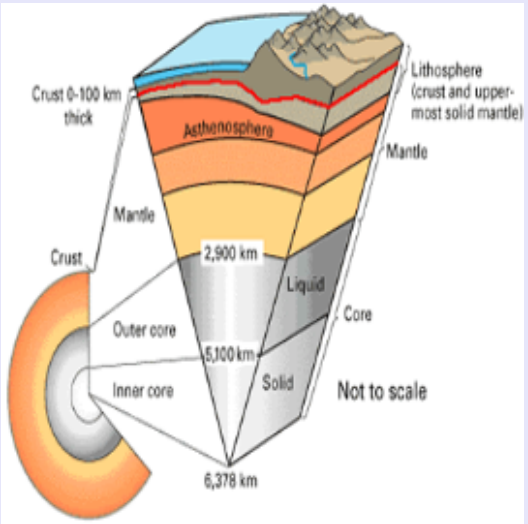


Image from: http://geology.com/articles/mohorovicic-discontinuity.shtml

Photo from: http://en.wikipedia.org/wiki/File:%D0%9A%D0%BE%D0%BB%D1%8C%D1%81%D0%BA%D0%B0%D1%8F_%D1%81%D0%B2%D0%B5%D1%80%D1%85%D0%B3%D0%BB%D1%83%D0%B1%D0%BE%D0%BA%D0%B0%D1%8F_%D1%81%D0%BA%D0%B2%D0%B0%D0%B6%D0%B8%D0%BD%D0%B0_crop.jpg

Sources: http://en.wikipedia.org/wiki/Kola_Superdeep_Borehole
http://www.damninteresting.com/the-deepest-hole

Kola Borehole

What Did We Learn?

- seismic waves travel faster at a depth of between 3 to 6 km below the earth's surface, and geologists had surmised that this was due to a transition from granite to basalt

- this long-held belief was found to be untrue; instead it was found to be a change in the rock (metamorphic) brought on by the extreme heat and pressure at that depth

- geologists were shocked to discover that this rock was saturated with water, even though it was thought that water would not exist at such a depth

- the Kola borehole reached rock from the Archaen age (greater than 2.5 billion years old)

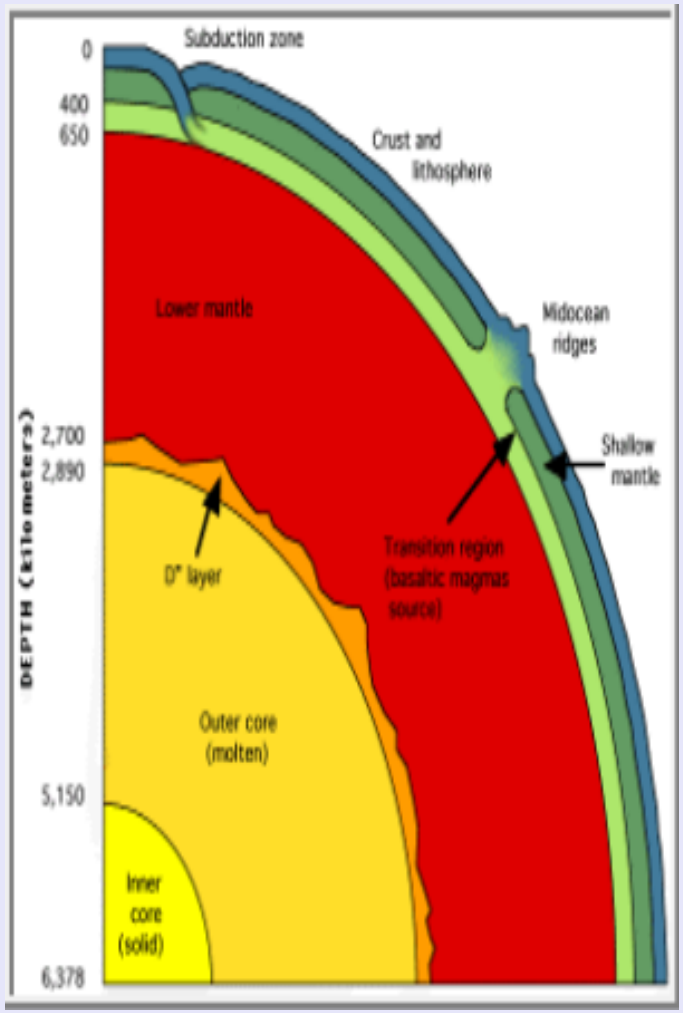


Image from: http://www.equalparenting-bc.ca/funstuff/planet-earth.htm

Sources: http://en.wikipedia.org/wiki/Kola_Superdeep_Borehole
http://www.damninteresting.com/the-deepest-hole

Direct evidence about the upper mantle is found only scattered places over the surface of the earth where rocks very different from those commonly found at the surface have been thrust up by movements of the ocean floors.

One place where unusual upper mantle rocks can be directly seen is in Gros Morne National Park in Newfoundland.

They were thrust up above sea level during the formation of the Appalachian Mountain belt, when North America, Europe, and Africa collided in the Paleozoic Era.

Rocks are exposed here from the mantle.

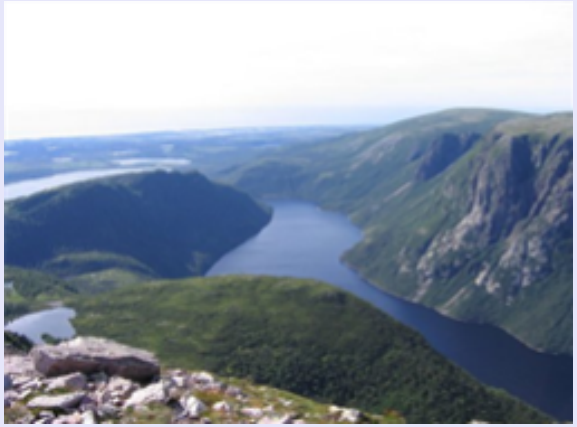


Photo: http://www.unescoworldheritagesites.com/gros-morne-national-park_canada.htm

References: Birchall, G. & McCutcheon, J. (2003). Planet Earth: A physical georgraphy. Toronto: John Wiley & Sons.

Uncovering the Earth's Interior

Although the Kola Superdeep Borehole provides us with valuable direct evidence of what the earth's interior consists of, much of what we know about it comes from "indirect" evidence.

The three different sources of indirect information are:

1) **the study of meteorites**

Photo from: http://commons.wikimedia.org/wiki/File:Estherville.jpg

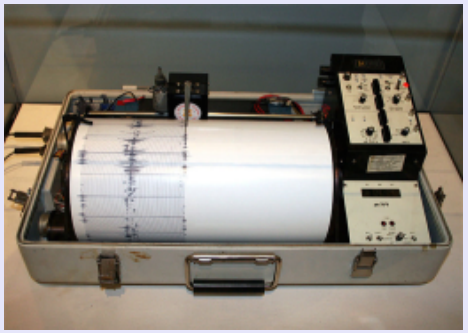


Photo from: http://commons.wikimedia.org/wiki/File:Kinemetrics_seismograph.jpg

2) **seismology**

3) **seismic tomography**

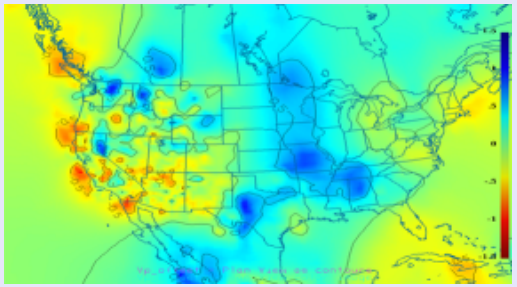


Image from: http://geon.unavco.org/unavco/IDV_datasource_tomo.html

Source: Birchall, G. & McCutcheon, J. (2003). *Planet earth: A physical georgraphy*. Toronto: John Wiley & Sons.

INDIRECT EVIDENCE

Meteorites

Meteorites are fragments of asteroids and former planets that broke up when they collided with other celestial bodies out in space.

It is believed that these asteroids and small planets (known as planetesimals) formed in the same way and from similar materials as the earth.

By studying meteorites, we can make certain inferences about the earth's interior, depending on the compositions, which fit into the three main categories of iron-nickel, stony, and stony-iron.

Photo from: http://commons.wikimedia.org/wiki/File:The_2010_Perseids_over_the_VLT.jpg

A stony-iron meteorite that fell in Emmet County, Iowa, on May 10, 1879.

Iron-nickel meteorites are believed to have come from the cores of their original bodies, stony meteorites from areas similar to the earth's mantle, and stony-iron from the area between the core and mantle. Thus, information about the interior of the earth can be inferred from the characteristics and densities of meteorites.

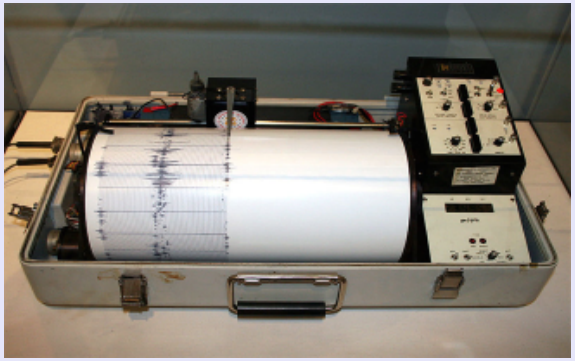
INDIRECT EVIDENCE

Seismology

Seismology is the scientific study of earthquakes, the seismic waves they generate, and the passage of those waves through the earth's interior.

The energy released from an earthquake causes seismic waves to move outward from its centre or *focus*.

Seismographs all over the world are used to record information from the waves of earthquakes.



Video: Earth's Interior (7:11 - 10:10)
http://learning.aliant.net/

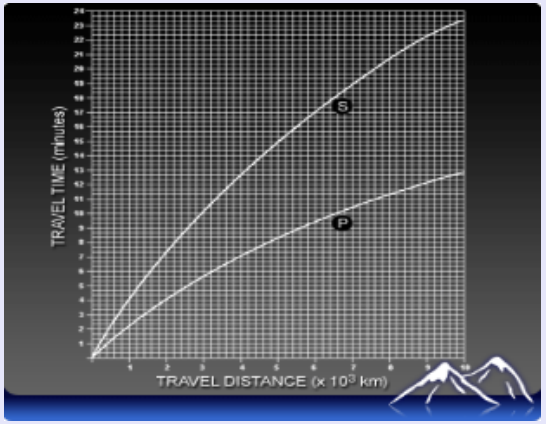


Image from: http://learn.uci.edu/oo/getOCWPage.php?course=OC0811004&lesson=003&topic=006&page=14

Three main types of waves are generated by earthquakes:

1. P or primary waves: the fastest moving waves, they are compressional and can penetrate through solid and liquid

2. S or secondary waves: the slower moving, transverse waves that can only penetrate through solids

3. L or long waves: also known as surface waves, are the waves that travel along the surface of the earth

SEISMOLOGY

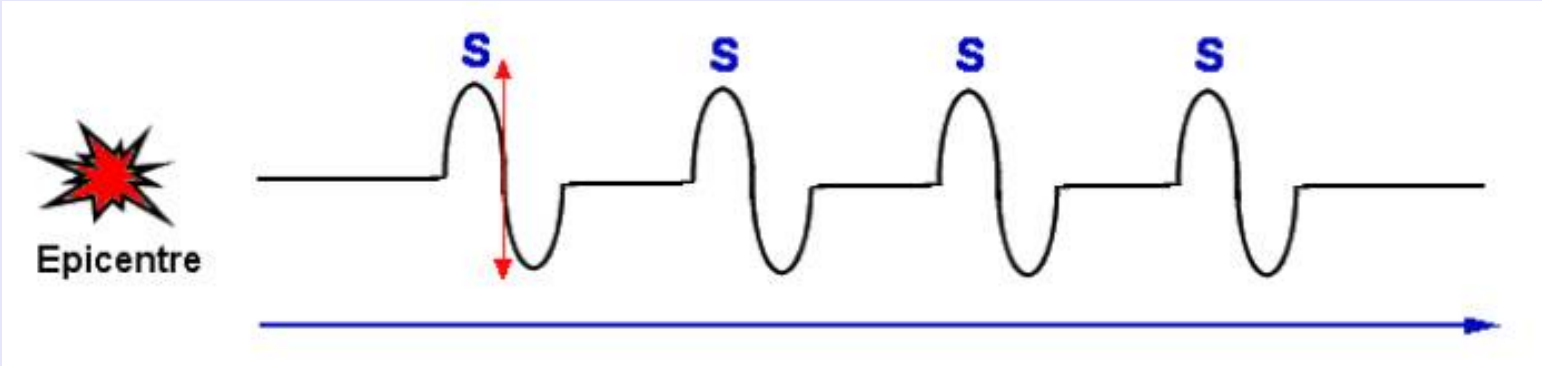


Image from: http://commons.wikimedia.org/wiki/File:S_sismic_wave.jpg

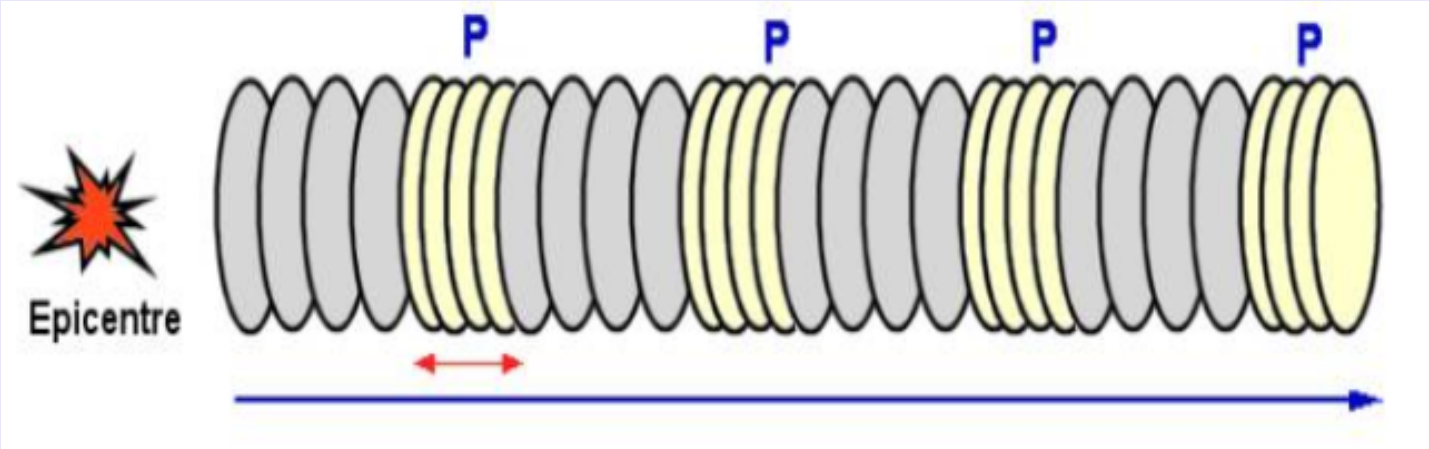


Image from: http://commons.wikimedia.org/wiki/File:P_sismic_wave.jpg

Refraction of Earthquake Waves as They Pass Through Layers of Different Densities

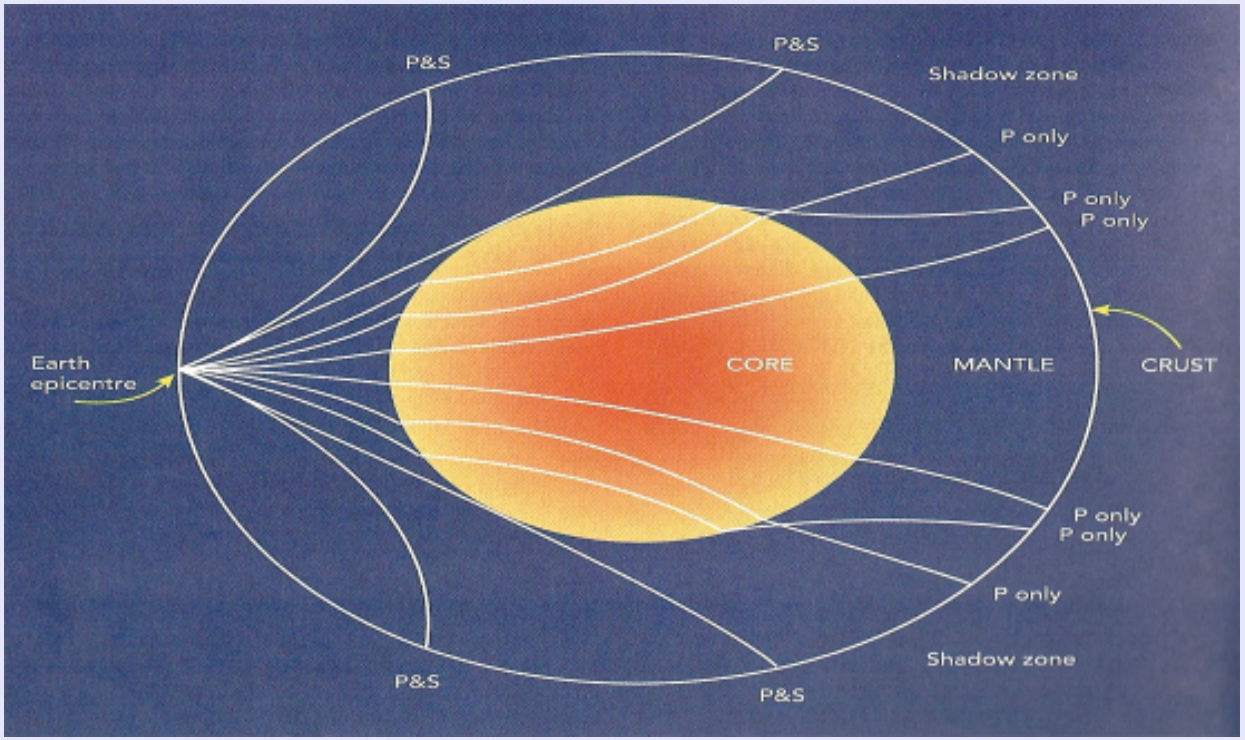


Image from: Birchall, G. & McCutcheon, J. (2003). *Planet earth: A physical georgraphy*. Toronto: John Wiley & Sons.

Intro to Shadow Zones

http://www.iris.edu/hq/programs/education_and_outreach/animations/18

Shadow Zones

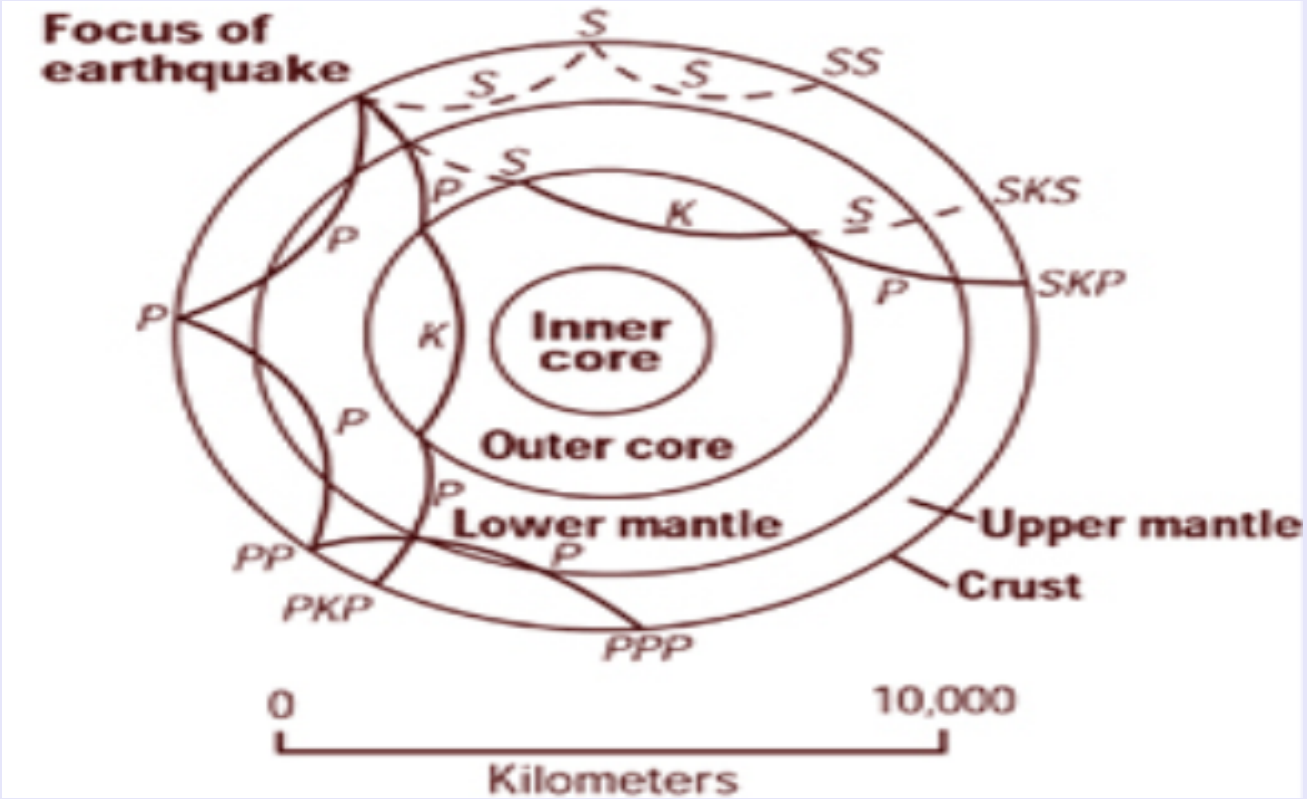


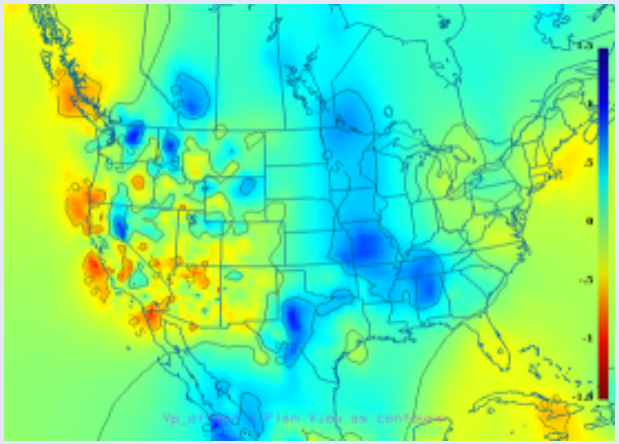
Image from: http://en.wikipedia.org/wiki/File:Earthquake_wave_paths.svg

For further information on the passage of S and P waves through the earth, go to:

http://www.iris.edu/hq/programs/education_and_outreach/animations/18

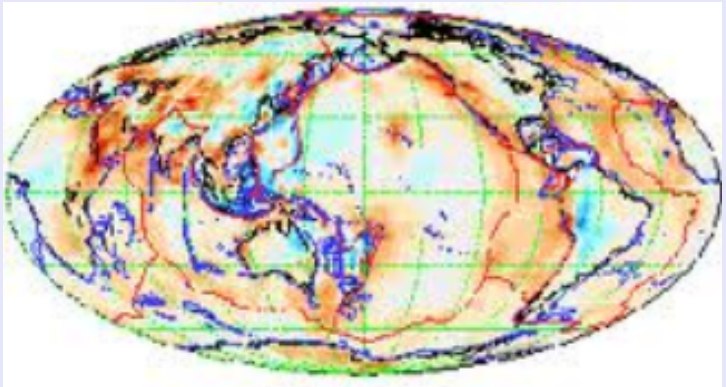
INDIRECT EVIDENCE

Seismic Tomography



Seismic tomography uses data from hundreds of seismic stations around the world to determine where variations in the earth's density and temperature occur.

Earthquake waves will slow down in hotter, less dense rocks, and they will speed up in cooler, denser areas in the mantle.



Data from a number of seismic stations is compiled to produce a three-dimensional view of the earth's interior, much the same way that images from a CAT scan show the interior of the human body.

Confused?

Overwhelmed?

Still thinking about taking on the Giant Chameleon
in the Mammoth Mushroom Forest?

Check out . . . .

IRIS

Incorporated Research Institutions for Seismology

http://www.iris.edu/hq/

http://www.iris.edu/seismon/

for amazing videos and resources for use in the classroom.

GLOSSARY

Geography terms related to the structure of the earth

Core - the innermost layer of the earth's interior, believed to be composed of a mixture of iron, nickel, and traces of other heavy metals, which is divided into a solid inner core and a liquid outer core.

Crust - the thin, solid, outer layer of the earth that is chemically different from the mantle rocks below.

Mantle - the layer of the earth's interior differing in chemical composition from the crust above and the core below and having a density ranging from 3.0 to 3.3 g/cc.

Meteorite - matter that has fallen to the earth's surface from outer space.

P (Primary) Waves - the fastest moving compressional* earthquake wave that passes through both the solid and liquid layers of the earth's interior.

***compressional** - they alternately push (compress) and pull (dilate) the rocks through which they pass.

S (Secondary) Waves - slower, transverse waves that travel through the rock by moving it from side to side. These can only pass through solids.

Seismology - the scientific study of earthquakes, the seismic waves they generate, and the passage of these waves through the earth's interior.

Seismic Tomography - a computer technique that analyses earthquake waves recorded at hundreds of seismic stations to produce maps showing variations in the density and temperature of the earth's mantle.

References: Birchall, G. & McCutcheon, J. (2003). Planet Earth: A physical georgraphy. Toronto: John Wiley & Sons.

RESOURCES

Article: Holladay, A. (2006). How scientists determine the composition of each planet. The Associated Press

http://www.usatoday.com/tech/columnist/aprilholladay/2006-09-25-measuring-planets_x.htm

Article: Bellows, A. (2007). The deepest hole. Damn Interesting.

http://www.damninteresting.com/the-deepest-hole

Interactive Map - Earthquakes: Incorporated Research Institutions for Seismology. Seismic Monitor.
http://www.iris.edu/seismon/

Textbook listed in curriculum document: Birchall, G., & McCutcheon, J. (2003). Planet Earth: A physical georgraphy. Toronto: John Wiley & Sons.

Video: Earth Revealed Series. (2000). Earth's Interior. Bell Aliant Learning Centre. http://learning.aliant.net.
*Note: must be logged in to see the video. I had problems viewing it in both Firefox and Chrome. Explorer worked though.
Watch from 7:11 to 10:10

Website: Incorporated Research Institutions for Seismology (IRIS).
http://www.iris.edu/hq/